10/565964
IAP9 Rec'd PCT/PTO 26 JAN 2006

Circuit arrangement for cooling charge air and method for operating a circuit arrangement of this type

The invention relates to a circuit arrangement for cooling charge air in a motor vehicle equipped with a turbocharger in accordance with the preamble of claim 1, and to a method for operating a circuit arrangement of this type.

According to the prior art, to increase the power of engines, turbochargers are used in order to increase the throughput of air in the engine. In the compression needed for this, the air, designated below as charge air, is however heated because of the compression in the turbocharger. To compensate for the loss of density associated with the heating of the charge air, i.e. in order to increase the air density, air coolers are used which are arranged at the front in the cooling module and serve for cooling the charge air. The charge air in this case flows through a heat exchanger, through which ambient air flows and which is consequently cooled. It is thereby possible to cool the charge air to a temperature which is approximately 15 K above the temperature of the ambient air.

It is furthermore known that the cooling of the charge air takes place via a coolant circuit, for example a low-temperature circuit, in which the coolant is cooled to very low temperatures. By means of this cold coolant, the charge air is cooled down to a predetermined cooling temperature in a charge air/coolant cooler. For the connection of the low-temperature circuit, there are two variants, namely an integration of the low-temperature circuit into a secondary circuit of the engine cooling system or a design in the form of a separate circuit.

If the engine output is to be further increased, the known supercharging systems have their limits, in respect of supercharging rate and response characteristics, at low load.

The object of the invention is to improve a circuit arrangement of the type mentioned in the introduction.

This object is achieved by a circuit arrangement having the features of claim 1.

According to the invention, a circuit arrangement is proposed comprising a low-temperature circuit for cooling charge air that is fed to an engine in a motor vehicle equipped with a turbocharger, characterized in that the charge air is compressed in two stages in a first low-pressure turbocharger and a second high-pressure turbocharger, where, in order to cool the charge air, a first cooler is provided downstream of the low-pressure turbocharger and upstream of the high-pressure turbocharger, and a second cooler is provided downstream of the high-pressure turbocharger and upstream of the engine. By means of the intermediate cooling downstream of the first low-pressure turbocharger, it is possible to ensure that excessively high air temperatures do not arise, as a result of which the service time of the used components, which are exposed to the high temperatures, can be increased. The two-stage cooling exhibits an advantageous dynamic behavior. Since the intermediate cooling in partial load takes up scarcely any thermal loads, the coolant contained in the low-temperature circuit is cooled to a low temperature level just above the ambient temperature. This results in a substantial cooling power reserve which can be utilized when switching to high engine load.

The installation space required is relatively small compared to the known solutions, since, despite the

intermediate cooling, there is only one charge air line to and from the cooling module, and only one coolant-cooled charge air cooler to be arranged near the engine.

A low-pressure charge air/coolant cooler is preferably provided for the first cooling of the charge air, and a high-pressure charge air/air cooler is provided for the second cooling of the charge air. In this case, stability problems are avoided in the air-cooled high-pressure charge air/air cooler particularly through the intermediate cooling.

The installation space can be utilized optimally by virtue of the fact that the high-pressure charge air/air cooler is arranged directly alongside a low-temperature cooler and, seen in the direction of air flow of the cooling air, upstream of a main coolant cooler. The front face of the low-temperature cooler takes up preferably 20% to 50% of the total front surface.

According to a preferred variant, the low-temperature circuit is part of an engine cooling circuit, but it can also be designed separately from this, and a control system for cutting down on costs is not absolutely essential. Also possible is an intermediate cooling with air and/or a cooling of the charge air downstream of the second compression stage with the aid of a coolant.

The invention is explained in detail below on the basis of two illustrative embodiments and with reference to the drawing, in which:

Fig. 1 shows a circuit arrangement according to the first illustrative embodiment,

Fig. 2 shows a circuit arrangement according to the second illustrative embodiment,

Fig. 3 shows a graph which shows the outlet temperature of the second compressor stage over the outlet temperature of the intermediate cooling, and

Fig. 4 shows a graph which shows the front face portion of the low-temperature cooler over the outlet temperature of the intermediate cooling.

Fig. 1 shows a circuit arrangement K which serves for cooling two successive turbochargers, namely a low-pressure turbocharger 1 and a high-pressure turbocharger 2. The charge air designated by reference label 13 is sucked in from the environment and compressed in the low-pressure turbocharger 1 in a first stage. In so doing, the temperature of the charge air 13 increases. To achieve a further compression without adversely affecting the service life as a result of overheating of the structural parts in direct or indirect contact with the charge air 13, which is the case of aluminum at temperatures starting from about 230°C, the compressed charge air is cooled in a low-pressure charge air/coolant cooler 3 which is part of a low-temperature circuit NK. The low-temperature circuit NK is discussed in more detail below.

After the cooling in the low-pressure charge air/coolant cooler 3, the charge air 13 passes into the high-pressure turbocharger 2 in which it is further compressed to its end pressure, which is in turn associated with heating. In order to increase the charge air density in the (combustion) engine 8, the hot charge air 13 is cooled in a charge air/air cooler 4 before being fed to the engine 8. As a result of the intermediate cooling, it is possible to ensure that the maximum charge air temperatures after the last

turbocharger stage remain limited to a degree which permits the use of air-cooled charge air coolers (cf. Fig. 3). This is advantageous in respect of the costs and the available installation space.

The low-pressure charge air/coolant cooler 3 for the intermediate cooling is arranged near the engine and is supplied by the separate low-temperature circuit NK. An air cooler, hereinafter referred to as low-temperature cooler 5, is provided in the low-temperature circuit NK and is traversed by the low-temperature coolant 14 flow in connection with the low-pressure charge air/coolant cooler 3.

As is shown in Fig. 1, the low-temperature cooler 5 is arranged directly next to the high-pressure charge air/air cooler 4, both of which, seen in the direction of flow of the cooling air 15, are arranged upstream of a main coolant cooler 6. The air is sucked in by a fan 7 which is arranged behind the main coolant cooler 6. The low-temperature cooler 5 is dimensioned such that its end face takes up between 20% and 50% of the maximum possible end face in the cooling module (see Fig. 4). Alternatively, the low-temperature cooler 5 can also be arranged in the air flow upstream of the air-cooled high-pressure charge air/air cooler 4.

The coolers are in this case arranged in such a way that coolers which are at a low medium temperature level are positioned in the cold cooling air stream and coolers which are at a high temperature level are positioned in the warm cooling air stream.

The low-temperature coolant 14 flows onward to the pump 10, which ensures circulation of the coolant 14, and from there back to the low-pressure charge air/coolant cooler 3.

According to the present illustrative embodiment, the low-temperature coolant circuit NK is not controlled; it can be set in such a way that the best possible charge air cooling is achieved but boiling problems in the coolant 14 cannot however occur. The low-temperature coolant circuit NK contains relatively little coolant 14. The boiling problems are easily avoided because very high charge air temperatures do not occur at the outlet of the first compressor stage.

The engine 8 is cooled by an engine cooling circuit MK in which an engine coolant 12 flows. The coolant 12 cooled in the main coolant cooler 6 is fed to the engine 8 via the pump 9. The control of the cooling performance is effected via a bypass thermostat 11 in a manner known per se.

Figure 2 shows a circuit arrangement K according to a second illustrative embodiment which essentially coincides with that of the first illustrative embodiment unless otherwise described below. The same reference labels are used here.

In a departure from the first illustrative embodiment, no separate low-temperature circuit NK is provided in the second illustrative embodiment. The coolant 14 is instead branched off from the engine cooling circuit MK from the pressure side of the pump 9 and is fed to the low-temperature cooler 5. In the low-temperature cooler 5, the coolant 14 is sharply cooled and then flows to the coolant-cooled low-pressure charge air/coolant cooler 3, where it serves for the intermediate cooling of the charge air 13. The coolant 14 is then mixed again at the engine outlet with the coolant stream of the engine cooling circuit MK.

List of reference labels

1	low-pressure turbocharger
2	high-pressure turbocharger
3	low-pressure charge air/coolant cooler
4	high-pressure charge air/air cooler
5	low-temperature cooler
6	main coolant cooler
7	fan
8	engine
9	pump
10	pump
11	thermostat
12	coolant
13	charge air
14	low-temperature coolant
15	cooling air
K	circuit arrangement
MK	engine cooling circuit
NK	low-temperature circuit